ECOLOGIC AND MORPHOLOGIC STUDY OF THE CLOVERS (TRIFOLIUM).

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(*Read April 21, 1922.*)

This study of the clovers was begun in 1907 and has been pursued intermittently ever since. Sufficient data has accumulated to warrant its assemblage for publication. The material for investigation was gathered in the open for all of our common species, numbering about six, and the remainder was raised from seeds planted in pots in the greenhouse. After considerable correspondence, which was seven years before the outbreak of the world war, seeds were obtained from Ames (Iowa), Amsterdam (Holland), Berlin (Germany), Besancon (France), Burlington (Vermont), Cambridge (England), Copenhagen (Denmark), Dijon (France), Dublin (Ireland), Hamburg (Germany), Innsbruck (Austria), Kew (England), Knoxville (Tennessee), Lincoln (Nebraska), Northampton (Massachusetts), Rome (Italy), St. Louis (Missouri), St. Petersburg = Petrograd (Russia), Tiflis (Persia), Tucson (Arizona), Vienna (Austria), Washington (District of Columbia). The seeds from Washington, D. C., were obtained from agrostologists connected with the United States Department of Agriculture and from the Bureau of Foreign Seed and Plant Introduction. Some seeds were purchased from dealers in New York and Philadelphia. The trial sowings of these seeds showed that most of them readily germinated, but some of them were refractory, or failed to sprout entirely. The seedlings and young plants intended for histologic investigation were fixed in chromacetic acid and finally put into 50 per cent. alcohol for preservation. The growing plants were used for experimentation on their leaf movements.

Number of Seeds in the Pods.

Some of the material received from botanical gardens had not been hulled and it was thought worth while to determine how many seeds

were found in the pods of each species, which were sent in the uncleaned condition. The samples of *Trifolium repens* showed from 1–4 seeds in each legume. *Trifolium elegans* and *T. montanum* had 1–3 seeds. *Trifolium resupinatum, T. rubens,* and *T. suffocatum* yielded 1–2 seeds. The following species, arranged alphabetically, had only one seed in each pod, and this held good for these species from different countries: *agrarium, alexandrinum, alpestre, angustifolium, arvense, badium, bocconi, dubium, elegans, incarnatum, johnstoni, leucanthum, maritimum, medium, minus, montanum, nivale, ochroleucum, pannonicum, pratense, procumbens, reclinatum, repens, repens* var. *macrorhiza, resupinatum, rubens, scabrum, spadiceum, squarrosum, stellatum, striatum, suffocatum.*

Weight of Seeds.

The weight of the seeds was determined in milligrams. Some of the samples were sufficiently large to permit the weighing of one hundred seeds of each. Others contained only a small number of seeds, so that ten was the maximum number the weight of which could be determined. In order that the results might be made comparable, the weights in each case are calculated on the ten basis. Of course, the weighings were more accurate where the larger numbers were used. In some cases fifty seeds and in others twenty-five seeds were weighed. In the accompanying list the weights determined by weighing 100, 50, 25 seeds are placed in ordinary type. The weights originally determined on the ten basis are printed in heavy-faced type. The weights of the seeds of the various species of Trifolium are in milligrams: *agrarium* (2, 5, 3.2, 5), *alexandrinum* (30, 31.5, 32.5, 34), *alpestre* (10, 12, 15.5), *altissimum* (17), *angustifolium* (12, 14), *arvense* (2, 2.5, 4), *aureum* (3), *balansæ* (5.4), *bocconi* (3, 5.5), *campestre* (1.2), *cernuum* (2), *dubium* (3.3), *elegans* (4.5, 6.5, 7.5), *filiforme* (4.5, 5, 5.5, 5.6), *glomeratum* (2.5, 3), *hybridum* (5,5, 5,5,5, 7, 7.5, 8,8) *incarnatum* (30, 32.3, 36, 36.5, 36.5, 37, 42.5), *johnstoni* (5.3), *lupinaster* (17), *maritimum* (15, 17, 25), *medium* (12.5, 12.5, 13), *minus* (3.3, 5), *montanum* (5, 6.5, 7.5, 10, 11), *nivale* (5), *pannonicum* (28, 33, 36.5, 37, 40, 41), *patens* (6.5), *perreymondi* (3), *pratense* (13, 13.5, 14, 15, 15, 16, 16, 16.5, 17, 19.5, 20, 22, 25),

pratense perenne (18.5), *pratense* × *medium* = Sutton's cowgrass (21), *pratense* × *pratense* × *medium* = Sutton's giant hybrid cowgrass (19.5), *procumbens* (2.5, 2.9, 5), *reclinatum* (30, 31), *reflexum* (6, 6.5), *repens* (2, 3, 3.5, 3.7, 5.5, 5.5, 7, 7, 7, 7.5, 8), *repens* var. *macrorhiza* (5.5), *repens perenne* (7.5), *repens* var. (4.7), *resupinatum* (8.5, 10, 11), *rubens* (18, 18.5, 19.5, 21, 22.5, 23.5), *scabrum* (1, 2, 4.5), *spadiceum* (5), *spumosum* (2.5), *squarrosum* (15), *striatum* (20, 20.6), *suaveolens* (16.5), *subterraneum* (26, 34, 119.6[1]), *tridentatum* (13.5). If we classify the species according to the weight of their seeds into light-seeded, medium-seeded, heavy-seeded, we would have the following arrangement of them:

Light-seeded Clovers.—agrarium, arvense, aureum, balansæ, bocconi, campestre, cernuum, dubium, elegans, filiforme, glomeratum, hybridum, johnstoni, minus, montanum, nivale, patens, perreymondi, procumbens, reflexum, repens and varieties, *scabrum, spadiceum, spumosum.*

Medium-weight Seeds.—alpestre, altissimum, angustifolium, lupinaster, maritimum, medium, pratense, squarrosum, suaveolens, tridentatum.

Heavy-seeded Clovers.—alexandrinum, incarnatum, pannonicum, reclinatum, rubens, striatum, subterraneum.

The weight of seeds is an important matter to know in buying seeds for farming operations by bulk, and also it can be used in helping to identify doubtful seed samples, as there are general specific differences in the weight of seeds. There is some degree of correlation between the weight of clover seeds and their size. The larger seeds are heavier than the smaller ones. It is probable that the differences in the weight of two samples of the same species of clover are due also to a difference in their age. The older seeds, having lost water in drying, are, of course, lighter than the younger seeds, which have not dried out to the same extent. The variation in weight may be due to the fact that they have been derived from different countries, and, therefore, grew under totally different conditions.

[1] This apparently large discrepancy is due to the fact that the seed size and weight varied more in this species than in any other.

Seedling Clovers.

An examination of the large number of seedlings raised from seeds obtained from the different places mentioned above shows that they may be classified into several groups according to the sizes of the cotyledons. The following details are taken from the natural-sized drawings of all the seedlings raised during their experimental study (Plates I, II, III). The species of Trifolium with large cotyledons are: *alexandrinum, angustifolium, incarnatum, pannonicum, pratense.* Those with middle-sized seed leaves are: *agrarium, alpestre, angustifolium, maritimum, medium, procumbens, ochroleucum, reclinatum, spumosum, striatum, subterraneum.* The clovers which showed small cotyledons on germination are: *arvense, aureum, badium, balansæ, bocconi, campestre, cernuum, elegans, filiforme, glomeratum, johnstoni, lupinaster, minus, montanum, patens, perreymondi, resupinatum, rubens, scabrum, spadiceum, suffocatum.* The clovers with narrow cotyledons are: *agrarium, angustifolium, bocconi, campestre, filiforme, glomeratum, maritimum, patens, reclinatum, repens, scabrum.* Those with broad seed leaves are: *alexandrinum, alpestre, badium, elegans, incarnatum, lupinaster, minus, ochroleucum, pannonicum, pratense, resupinatum, spadiceum, spumosum, stellatum.* The length of the hypocotyl and radicle together varied from 7 mm. in *T. johnstoni,* 8 mm. in *T. scabrum,* to 60 mm. in *T. incarnatum.* All of the radicles developed root hairs in greater or less numbers. The accompanying plates (Plates I–III) give the general form and appearance of the clover seedlings examined.

Morphologic Variations in the Clovers.

It is not intended to make an exhaustive survey of morphologic variations in the clovers, but to briefly describe those which came under the personal observations of the writer.

Double-headed Red Clover.—In July, 1911, at Belmar, N. J., were found two red clover plants in which the heads were double. The twin heads were separated down to the middle and were united by their lower halves. The flowers were of the usual structure and color.

Statistical Study of Red Clover Variations.—The usual statements in the manuals of botany about the size and other characteristics of the organs of the species included in the manual are not based on accurate measurements for statistical purposes. In order to provide such data for the common species of Trifolium, measurements were made of one hundred red clover plants as a beginning.

The length of the petioles above the stipules of one hundred leaves varied from 271 mm., the longest, to 38 mm., the shortest. The length of the middle leaflet of the three leaflets varied from 44 mm., the longest, to 15 mm., the shortest. The widest middle leaflet was 29 mm., and the narrowest 12 mm. Similarly measurements were made of the right and left leaflets of the trio with the following results:

Longest Left Leaflet	42 mm.
Shortest Left Leaflet	15 mm.
Widest Left Leaflet	26 mm.
Narrowest Left Leaflet	12 mm.
Longest Right Leaflet	43 mm.
Shortest Right Leaflet	13 mm.
Widest Right Leaflet	29 mm.
Narrowest Right Leaflet	10 mm.

Out of 100 leaves, 78 had leaflets with retuse apices and 22 had leaflets with obtuse apices. The three leaflets of our common field red clover are marked usually (89 out of 100) with U-shape, or V-shaped, whitish blotches, as if one had placed a dab of white paint on the leaflets with the fleshy part of the thumb. In some cases these markings are pale, in other cases prominent. Eleven plants in one hundred were found entirely without the thumb-mark spots. Sometimes a red clover plant has been found in which the white color runs along the veins in streaks toward the midribs of the leaflets. This arrangement of color may be due the action of an enzyme in producing the variegation, or to the presence of air beneath the surface in the V-shaped area. A little boy, Roger M. Hinckley, aged 11, writes to St. Nicholas (1909) from Greenfield, Mass., about a crinkly-leaved white clover with leaflets panduriform. A figure is given of this variation, probably induced by disease.

Four red clover plants had leaves with glabrous (smooth) petioles and 96 red clover plants of my collection had petioles that were hirsute. Five clover plants in one hundred had blotched leaves and 95 were unblotched. This descriptive presentation of the statistical study of one hundred red clover plants has been adopted instead of the tabular form to save the cost of the printing of the accumulated data in the form of a table.

Clover Habitats and Growth Forms.

The various habitats described with reference to the species of clover found growing in them were taken from the descriptive labels of the herbarium sheets found in the herbarium of the Botanical Department, University of Pennsylvania, the Academy of Natural Sciences of Philadelphia, the U. S. National Herbarium, Washington, D. C., the New York Botanical Gardens, and Kew Gardens, London, England. The habitats are arranged beginning with the hydrophytic ones and ending with the driest, most xerophytic ones.

Wet Places.—Trifolium amplectens (California), *anodon* (California), *arizonicum* (California), *barbigerum* (California), *bolanderi* (California), *cyathiferum* (California, Oregon), *harneyensis* (Oregon), *howellii* (Oregon), *megacephalum* (Oregon), *melananthum* (California), *microcephalum* (Washington), *oreganum* (Washington), *pauciflorum* (Washington), *pedunculatum* (Oregon), *rydbergii* (Montana), *scabrellum* (California), *splendens* (California), *truncatum* (California), *variegatum* (California).

Salt Marsh Edge.—Trifolium flavulum (California).

Gravelly River Bar.—Trifolium heterodon (Washington).

Meadows.—Trifolium andrewsii (California), *beckwithii* (Oregon), *harneyensis* (Oregon), *involucratum* (Washington), *longipes* (California), *macræi* (California), *monanthum* (California), *plumosum* (Idaho), *polydon* (California), *reflexum* (Arkansas), *rusbyi* (California), *spinulosum* (California), *tridentatum* (California), *triste* (California), *wormskioldii* (California).

Pampas.—Trifolium matthewsii (Argentina).

Prairies.—Trifolium altissimum (Washington), *amphianthum* (Texas), *bejariense* (Texas), *carolinianum* (Texas), *douglasii* (Washington), *pauciflorum* (California).

Open Gravelly Mountain Slopes.—Trifolium virginicum (West Virginia).

Rocky Woods.—Trifolium aureum (Maryland).

Calcareous Bluffs.—Trifolium mexicanum (Mexico).

Pine Woods.—Trifolium barbigerum (California), *microcephalum* (California), *microdon* (California), *splendens* (California), *stenophyllum* (California), *subcaulescens* (Colorado), *trichocalyx* (California), *variegatum* (California), *wormskioldii* (California).

Big Tree Groves.—Trifolium breweri (California).

Alpine.—Trifolium alpinum (Switzerland, Tyrol), *amabile* (Bolivia, Mexico), *attenuatum* (Colorado), *badium* (Pyrenees, France), *bracteolatum* (Colorado), *brandegei* (Colorado), *burchellianum* (Africa), *caudatum* (Phrygia), *chilense* (Bolivia), *calocephalum* (Africa), *dasyphyllum* (Colorado), *gemniflorum* (Colorado), *haydeni* (Montana), *involucratum* (Mexico), *lividum* (Wyoming), *montanense* (Montana), *nanum* (Colorado), *noricum* (Carniolia), *pallescens* (Switzerland), *parryi* (Colorado), *petrophilum* (California), *polystachyum* (Africa), *salictorum* (Nevada), *saxatile* (Switzerland), *schiedeanum* (Mexico), *semipilosum* (Africa), *subrotundum* (Africa), *stenolobium* (Colorado), *thalii* (Pyrenees).

The growth forms given on the labels of the herbarium sheets and also noted when the clovers were studied are:

Dwarf Alpine Plants with Large Tap Root.—Trifolium amabile (Bolivia), *andinum* (Wyoming), *anemophilum* (Wyoming), *barbigerum* (California), *bolanderi* (California), *bracteolatum* (Colorado), *chilense* (Bolivia), *dasyphyllum* (Colorado), *lividum* (Wyoming), *nanum* (Colorado), *pallescens* (Switzerland), *salictorum* (Nevada), *scariosum* (Montana, Wyoming).

Dwarf Rosette.—Trifolium andersonii (Nevada), *bolanderi* (California), *gymnocarpum* (Wyoming), *virginicum* (West Virginia).

Open Woodlands and Prairies.—Trifolium stoloniferum (United States).

Grass Steppes.—Trifolium acaule (Africa), *simense* (Africa).

Mesas.—Trifolium aciculare (California).

Sand Beaches.—Trifolium alexandrinum (Syria), *fucatum* (California), *heterodon* (Washington), *macræi* (California), *maritimum*

(England), *repens* (New Jersey), *tomentosum* (Island Porto Santa), *wormskioldii* (California).

Desert.—Trifolium gracilentum (California).

Pedregal.—Trifolium willdenovii (Mexico).

Prostrate Mats.—Trifolium gracilentum (California), *melananthum* (California), *resupinatum* (Madeira), *variegatum* (California).

Prostrate Xerophytes.—Trifolium depauperatum (California), *piluliferum* (Palestine).

General Geographical Distribution.

One fact which impressed the writer in the study of the clovers (Trifolium) at the Herbarium of Kew Gardens, London, England, in July, 1907, was the large number of species found in California, Oregon, Washington (Pacific North America), and in Palestine and Syria in the near east. In both cases the countries rich in clovers face western oceans, Palestine and Syria facing the Mediterranean Sea, and California, Oregon, and Washington the Pacific Ocean. "Orient" in the enumeration given below probably means the near east, and if the six North African species are deducted, as represented in the Kew Herbarium, there are 85 species from the orient. There are 14 species of clovers given in the second edition of Britton and Brown's "Illustrated Flora," and in the second edition of Small's "Flora of Southeastern United States" 3 species not given for the northern states, making 17 species in all. Seventeen species deducted from the number of North American species (86) in the Kew Herbarium gives 69 species as the number in Western North America, supporting in a general way the statement above, as to distribution in countries facing western oceans. The following numbers are derived from a list of clovers made while at Kew, and, although not complete, they are an indication in an approximate way of the numbers of species of Trifolium in different countries of the world: North African and Orient (91); North African (6); Northern Asia (7); China and Japan (3); India, Malaya (3); India (2); Australia, New Zealand (4); Tropical Africa (20); South Africa (14); North America (86); Central America (9); East Tropical South America

(8); West Tropical South America (1); Temperate South America (12).

Sleep Movements of Clover Leaves.

Pfeffer in his "Untersuchungen über die Entstehung der Schlafbewegungen der Blattorgane," Leipzig, 1907, does not undertake to investigate the clovers, although they provide more available material than *Albizzia lophantha, Mimosa Spegazzini, Phaseolus, Lourea vespertilionis, Mimosa pudica, Impatiens parviflora,* and *Siegesbeckia orientalis* investigated experimentally by him.

The gross morphologic movements are of interest (Plates D, E). The following species of clovers grown experimentally by the writer move their terminal leaflets into a flat vertical position in their nyctitropic movements: *Trifolium alpestre, arvense, dubium, elegans, filiforme, glomeratum, incarnatum, maritimum, minus, pannonicum, pratense* (mammoth), *pratense* × *pratense* × *medium, reflexum, resupinatum, rubens, spinosum.*

A few clover leaflets move so that the terminal leaflet is erect, but folded somewhat inwardly along the midrib. Such are *hybridum, ochroleucum, pratense, pratense* (old), and *subterraneum.* In these two cases the lateral leaflets move upward and inward so that their surfaces are applied together, the leaflets standing vertically as the figures clearly show. The following species of Trifolium show the terminal leaflets bent forward out of the vertical through an angle of 10° to 30° from the vertical: *alexandrinum, angustifolium, cernuum, elegans, hybridum, incarnatum, johnstoni, leucanthum, medium, perreymondi, reclinatum, striatum, tridentatum.*

In *Trifolium cernuum, elegans, medium, repens, perenne,* the terminal leaflets are folded along their midribs, so that their leaflets overlap the two lateral leaflets which stand vertically and lie parallel.

In *T. montanum, repens* (old), *repens perenne, scabrum,* the terminal leaflets are nearly horizontal, forming almost an angle of 90° with the vertical. The positions of the leaflets in *T. agrarium, aureum, badium, bocconi, campestre, patens, procumbens, stellatum* are different from the other species and are not suggestive of sleep movements. Whether the nyctitropic positions assumed in these clovers are due to experimentally unhealthy plants, future study of

them alone will reveal. The terminal leaflets of *Trifolium lupinaster* and *reclinatum* bend backward out of the vertical instead of forward. The accompanying 62 drawings will demonstrate better than words the actual position of the leaflets in the various clovers during nyctitropism (Plates IV, V).

Experimental Curves of Nyctitropic Clover Leaves.

The elaborate and rather costly piece of apparatus used by Pfeffer in his work, described and figured in Chapter II. of his work, was replaced by a simple home-made piece of apparatus (kymograph) consisting of a tin tomato-can mounted on an alarm clock with works altered to suit the conditions of the experiments. The tomato-can cylinder with registering paper was made to revolve once in two days instead of once every twelve hours by changing the motion of the bar turning the hour hand of the clock. The recording lever was poised on a fulcrum fastened to a cork pushed into the mouth of a test tube, which was then attached to the arm of a tripod, on the pan of which the potted clover plant was placed. A fine thread was attached to the clover leaflets by a thick solution of shellac and to the short arm of the registering lever. The long arm of this lever being twice as long as the short arm, the movements were thus magnified twice. The downward movements of the leaflets were transmitted into upward movements of the far end of the lever which traced the curve of movement on the glazed paper, which was covered with a coating of carbon by holding over a yellow gas flame after being placed on the cylinder. The curves represented in the accompanying figures were obtained in this way and were made permanent records by passing the blackened paper through a solution of shellac in 95 per cent. alcohol.

Fifty-five records were taken during the course of the experiments with the kymograph. The species of Trifolium, the movements of the leaflets of which were traced by curves, were as follows: 1, *resupinatum;* 2, *subterraneum;* 3, *incarnatum;* 4, *pannonicum;* 5, *elegans;* 6, *reclinatum;* 7, *alpestre;* 8, *spumosum;* 9, *leucanthum;* 10, *tridentatum;* 11, *pannonicum;* 12, *lupinaster;* 13, *pratense;* 14, *alpestre;* 15, *hybridum;* 16, *medium;* 17, *elegans;* 18, *balansæ;* 19,

stellatum; 20, *filiforme;* 21, *rubens;* 22, *dubium;* 23, *ochroleucum;* 24, *minus;* 25, *angustifolium;* 26, *elegans;* 28, *alexandrinum;* 29, *incarnatum;* 30, *striatum;* 31, *reclinatum;* 32, *patens;* 33, *maritimum;* 34, *rubens;* 35, *campestre;* 36, *maritimum;* 37, *cernuum;* 38, *bocconi;* 39, *hybridum* (old); 40, *agrarium* (mature); 41, *glomeratum;* 42, *incarnatum;* 43, *pratense* mammoth; 44, *pratense* (old); 45, *repens* (old); 46, *repens* var. *macrorhiza;* 47, *johnstoni;* 48, *pannonicum;* 49, *ochroleucum;* 50, *reclinatum;* 51, *procumbens;* 54, *reflexum;* 55, *pratense* × *pratense* × *medium;* 56, *badium;* 58, *perreymondi;* 59, *arvense;* 60, *aureum;* 61, *scabrum;* 62, *repens perenne;* 63, *agrarium* (young).[2] Not all of the records are good. Some of them are incomplete owing to the stoppage of the driving clock, or to the swinging of the level away from the recording cylinder owing to the disturbance of the lever stand. Occasionally the thread would break loose from the shellac fastening. As a result of these difficulties, some of the records are only part curves, and, therefore, can not be considered in the subsequent discussion. Only those records are discussed and illustrated which are fairly complete. It was found impracticable after the taking of the curve of the first species (*T. resupinatum*) to make the curve of temperature on the same record sheet as the curves of the leaflet movements. No attempt, therefore, was made to take the temperature in subsequent records. The relative humidity was not recorded in connection with the experimental study of the plants, nor was the relative amount of sunlight and cloudiness registered. Some changes in the curves of the night period suggest that it might have been advisable to have data on the times and intensity of the moonlight. The curves which are discussed in the following pages may be criticized, as approximations, because no record of temperature, humidity, sunlight, and cloudiness were kept in connection with them. This criticism is undoubtedly well founded, but the several complete curves are given, because they are suggestive of the character of the clover-leaf movements and may create enough interest for some one else to continue the careful investigation of such leaf movements as related to all of the influential environmental factors.

[2] The numbers here given apply to the drawings of seedlings (Plates I–III) and leaf movements (Plates IV–V).

Plant 1, Trifolium resupinatum (June 1 to June 4, 1908).—The terminal leaflet was attached to the string at 8 A.M., June 1. The curve was fairly level until the middle of the afternoon, when it began to rise with the approach of darkness. The steepest part of the curve was reached during the night, gradually sloping downward until morning. Some irregularities in the curve are noticeable on June 2. These may be due to cloudiness, for other records show that an overcast, or heavily clouded sky, causes the rise of the curve. This is especially noticeable on June 3, for there is a sharp rise after the depression of the morning. The sharp bumps in the curve of *Trifolium resupinatum* indicate the nyctitropic movements of the leaflets. The curve of Plant 2, *T. subterraneum,* demonstrates the same response of the terminal leaflets. There was a steady rise on June 3 in the afternoon, followed by a steep depression until nightfall, when the up curvature during night becomes a marked elevation, followed by a gradual depression until 9 A.M. on the following day, June 4.

Plant 9. Trifolium leucanthum (Plate V).—Experiments with this plant were started at 8 A.M. on June 2. The curve shows an upsweep in the forenoon, followed by a downward curvature in the middle of the day. At 3.20 P.M. we note a steep elevation, then a drop with a steep rise to 6.15 P.M., succeeded by a sharp drop of the curve and its reëlevation during the night. The curve taken on June 3 shows minor oscillations of the lever during the day and a sharp rise at 6 P.M. for the night. With the approach of day the curve drops uniformly until 8 P.M., when it rises slightly, dropping again at 9 A.M.

Plant 14, Trifolium alpestre.—This plant gave a curve which started at 11.20 A.M., June 4. It shows a uniform rise to the middle of the afternoon, then a drop and a sharp rise at nightfall. On the morning of June 5 there is a uniform drop of the curve with some oscillations until 3 P.M., when it begins to rise.

Plant 17, Trifolium elegans (Plate V).—The curve of leaf movements in this clover shows a gradual rise from the noon hour to late afternoon, with a sharp upward curvature at night, followed by a

depression the following day, June 5, and a sharp rise to the night position at 6 P.M.

The morning of June 6 showed a gradual downward movement of the curve until 9 A.M.

Plant 39, Trifolium hybridum.—A mature plant in flower gave a curve with a sharp valley and peaks. Starting at 12 M., June 10, it shows a sharp angular drop to 3 P.M., then a sharp rise and as sharp a depression during the late afternoon. After nightfall there was a precipitous rise during the night, then a sharp drop and a rise until about 10 A.M. on June 11. The curve then took a drop to noon, when it began to rain, and a sharp rise to the late afternoon, when it probably cleared. At 6 P.M. it made a steep up curvature during the period of night.

Plant 40, Trifolium agrarium (an old plant).—A lateral leaflet was tried, so that its curve does not correspond in general with the curves taken for the terminal leaflets. Starting at 11 A.M., June 12, we find the elevation of the curve is followed by a steep depression until 6 P.M., when the curve remains nearly horizontal until the next morning, when it rises rapidly to 9 A.M., followed by a depression until 3 P.M., when there is a rise to 6 P.M., and then a gradual fall.

Plant 42, Trifolium incarnatum (Plate V).—The curve of the crimson clover is fairly constant with an almost level depression during the day of June 10, a rounded elevation during the night, a depression with a sharp hump in the early morning of June 11 before 9 A.M., followed by a depression and a small rise after 12 M., when it began to rain. At 6 P.M. the upward movement of the curve for the night period is observable.

Plant 45, Trifolium repens.—An old mature plant in flower was studied as to the movements of the terminal and lateral leaflets. The curve for the terminal leaflet rose from 11 A.M., June 12, during the afternoon with a sudden downward movement to 6 P.M. The night period was characterized by a steep upward curvature followed by a drop during the small hours of the night, and a sharp rise before 9 A.M. on June 13. It is such a sharp rise which leads one to suspect that moisture may be a controlling factor. A rise of the curve to 3 P.M. is observable, and then a gradual downward curva-

ture to 6 P.M., when an upward movement is seen. The curve of the lateral leaflet of No. 45 is generally up during day and down during the night, with a steep downward gradient as the hour of sunrise is approached, with a sharp upward curvature in the daylight hours of the morning to 9 A.M. on June 11, then with a rainy morning, a downward movement is seen with an upward turn in the early afternoon.

Plant 48, Trifolium pannonicum (Plate V).—The middle leaflet of the compound leaf of this plant was connected with the kymograph at 11 A.M., June 12, with an oscillating movement of the curve downward to nearly 6 P.M., when the upward curvature during the night is clearly traceable. Daylight of June 13 shows a valley-like depression with sharp irregularities and a strong upward turn at nightfall. The same valley-like trough of the curve appeared for the daylight period of June 14, with a sharp rise on the afternoon of that day. Such sharp oscillations are inexplicable unless they are due to variations of temperature or humidity of the air. An inspection of the several curves in the accompanying plate will give a more adequate idea of the movements of the long arm of the recording lever. The above description will serve to draw attention to the more important features of the curves.

The writer desires to acknowledge the help given by Professor E. B. Ulrich in the arrangement of the details of the kymograph used in the experimental work. The kymographs used in the study of the clovers are essentially like the ones used by Professor Ulrich in his study of the "Leaf Movements in the Family Oxalidaceæ," published as a thesis[3] in part fulfillment of the requirements for the degree of Doctor of Philosophy at the University of Pennsylvania, received June, 1910.

EXPLANATION OF FIGURES OF THE SIX PLATES.

(Plates I–VI.)

1. *resupinatum.*
2. *subterraneum.*
3. *incarnatum.*
4. *pannonicum.*
5. *elegans.*
6. *reclinatum.*
7. *alpestre.*
8. *spumosum.*

[3] Contributions from the Botanical Laboratory, University of Pennsylvania, III. : 211–242.

9. *leucanthum.*
10. *tridentatum.*
11. *pannonicum.*
12. *lupinaster.*
13. *pratense.*
14. *alpestre.*
15. *hybridum.*
16. *medium.*
17. *elegans.*
18. *balansæ.*
19. *stellatum.*
20. *filiforme.*
21. *rubens.*
22. *dubium.*
23. *ochroleucum.*
24. *minus.*
25. *angustifolium.*
26. *elegans.*
27. *balansæ.*
28. *alexandrinum.*
29. *incarnatum.*
30. *striatum.*
31. *reclinatum.*
32. *patens.*
33. *maritimum.*
34. *rubens.*
35. *campestre.*
36. *maritimum.*
37. *cernuum.*
38. *bocconi.*
39. *hybridum* (old mature plant).
40. *agrarium* (old mature plant).
41. *glomeratum.*
42. *incarnatum.*
43. *pratense* (mammoth).
44. *pratense* (old mature plant).
45. *repens* (old mature plant).
46. *repens* var. *macrorhiza.*
47. *johnstoni.*
48. *pannonicum.*
49. *ochroleucum.*
50. *reclinatum.*
51. *procumbens.*
52. *rubens.*
53. *montanum.*
54. *reflexum.*
55. *pratense* × *pratense* × *medium.*
56. *badium.*
57. *pratense* (mammoth).
58. *perrcymondi.*
59. *arvense.*
60. *aureum.*
61. *scabrum.*
62. *repens perenne.*
63. *agrarium* (young).

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